3.0 AFO/CAFO Modeling Process

3.1 Changes to NWPCAM Since the Proposed Rulemaking

Table 17 contains a summary of major differences in the versions of the NWPCAM system used for the AFO/CAFO proposed rulemaking process and the final rulemaking process. These changes are described in detail elsewhere (RTI, 2002).

Table 17. Summary of Differences in NWPCAM Versions Used for the Proposed Rulemaking and Final Rulemaking

Component	Proposed Rulemaking (NWPCAM 1.5)	Final Rulemaking (NWPCAM 1.6)	Effect
Database Platform	Microsoft Access	Oracle	• Automated model runs • Streamlined quality control process • Simplified analysis of inputs or delivery ratios
Reach Network	• RF3 used to route loadings • RF3Lite used for chlorophyll-a modeling in lakes • RF1 used for in-stream modeling	• RF3 used to route loadings • RF3Lite used for in-stream modeling	• Improved network connectivity • Better coverage of open waters
Stream Flow	• RF3 stream flows based on average annual runoff by cataloging unit • RF1 stream flows based on RF1 characteristics data set	• RF3 stream flows calibrated using USGS gaging station data • Stream flows in western hydroregions adjusted for intermittent stream contribution	• Improved RF3 stream-flow estimates • Improved modeling accuracy

(continued)

Table 17. (continued)

Component	Proposed Rulemaking (NWPCAM 1.5)	Final Rulemaking (NWPCAM 1.6)	Effect
Slope by Cataloging Unit	Used one-half of average slope of first-order streams in the cataloging unit	Slope estimates based on Digital Elevation Model (DEM)	• More accurate slope estimates • Higher channel velocities and delivery ratios from land cells to RF3
Stream Velocity	• Velocity estimates based on Keup (1985) • Used RF1 characteristics database for in-stream modeling	All velocity estimates based on Jobson (1996)	Improved velocity estimates
PS Inventory	Used PS inventory from NWPCAM 1.1	Used PS inventory from NWPCAM 2.1	More comprehensive account of PS loadings
PS Delivery	PS loads routed directly to RF1	PS loads routed to RF3Lite with decay and transformation	Capitalizes on PS location information
Conventional NPS Loads	Based on county-level loadings apportioned to reaches	• Based on land-cover export coefficients • Incorporated the RUSLE for TSS loads on agricultural cells	• Improved spatial resolution • Improved consistency with nutrient approach • More accurate DO modeling
Nutrient NPS Loads	Export coefficients by hydroregion/ecoregion/ land-cover type calibrated to SPARROW nutrient fluxes	Same loadings, but speciated by land-cover type	Allows use of a water quality index that incorporates nutrient measures
Non-AFO/CAFO NPS Delivery	NPS loads routed to RF3Lite and RF1 without decay and transformation	NPS loads routed to RF3 and RF3Lite with decay and transformation	Improved consistency with PS load approach
AFO/CAFO Load Distribution	• Loads assigned randomly to agricultural cells within a county • Limited loads on land-use cells based on Beaulac and Reckhow (1982)	Loads assigned randomly to agricultural cells using model farms areas and without considering nutrient load caps	See Section 5.1

(continued)

Table 17. (continued)

Component	Proposed Rulemaking (NWPCAM 1.5)	Final Rulemaking (NWPCAM 1.6)	Effect
In-Stream Modeling of Nutrients	BATHTUB used to model chlorophyll-a at RF3Lite scale	NWPCAM 1.6 includes nutrient modeling at RF3Lite scale	• Permits use of a water quality index that includes nitrates and phosphates • Oxygen demand from non-AFO/CAFO nutrients will be modeled
In-Stream Modeling of Conventional Pollutants	Based on NWPCAM 1.1 kinetics with some peer-review comments incorporated	Based on NWPCAM 1.1 with all peer-review comments incorporated	Changes in kinetics are expected to have minimal impact on results
In-Stream Modeling of Bacteria	Included in-stream kinetics for FCB, but not FS	Includes in-stream kinetics for FCB and FS	Although not used in use support determination or benefits analysis, provides in-stream concentrations of FS
Benefits Metric	• WQL • Regionalized chlorophyll-a water quality ladder used to estimate economic benefits	Adds capability to calculate six-parameter WQI that includes nitrates and phosphates	Integrated economics benefits approach

3.2 AFO/CAFO Input Files

Four Microsoft Excel workbooks were supplied by EPA to characterize AFO/CAFO loadings to surface water:

1. AFO facility counts by county, animal type, and operation size[1]

2. Percentage of AFOs considered CAFOs in each state under various regulatory scenarios[2]

[1]File name = Distribution11.xls; Date received = 8/12/02

[2]Filename = StatePct(102502)corr.xls; Date Received = 11/15/02

3. Nutrient, sediment, BOD, and pathogen loadings for unregulated AFOs and regulated CAFOs under various technology options by U.S. region, animal type, and operation size. Model farm areas were also included in this data set.[3]

4. Speciation factors to break TN and TP loadings into nutrient species under various technology options by U.S. region, animal type, and operation size.[4]

Loadings were supplied for TN, TP, TSS, BOD, FCB, and FS. Loadings for each parameter were separated into manure, commercial fertilizer, and feedlot load categories.

3.3 Methodology

All preprocessing steps (i.e., the parts of NWPCAM 1.6 unaffected by the AFO modeling process) were outlined in Section 2.0 of this report. For each AFO/CAFO regulatory option modeled by NWPCAM 1.6, several analytical and data management processes were conducted:

- Distribute AFO/CAFOs and associated edge-of-field loadings to agricultural land-cover cells within each county.
- Route AFO/CAFO loadings from the land-cover cells to the nearest RF3 reach using an overland transport, loss, and transformation routine.
- Route AFO/CAFO loadings from the RF3 network to the RF3Lite subset using an in-stream transport, loss, and transformation routine.
- Simulate dilution, transport, and kinetics of the nutrients/pollutants in the RF3Lite network.
- Relate the nutrient and pollutant concentrations in the RF3Lite reach to beneficial use attainment criteria and goals.
- Calculate the overall WQI6.
- Compute economic benefits based on changes in water quality use-support.
- Compute economic benefits based on changes in WQI6.

See Section 2.1 for a flowchart of the NWPCAM 1.6 process employed for estimating the benefits of AFO/CAFO regulations using the Vaughn WQL approach.

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[3]Nutrients: File name = Output (11132002) adjusted Opt5.xls; Date received = 11/13/02

[4]File name = Speciation(1108).xls; Date received = 11/8/02

3.3.1 Method for Distributing AFO/CAFO Loadings

AFO/CAFO farm locations were supplied at the county level via county FIPS codes. In order to associate farms with RF3 reaches, the loadings were randomly distributed onto agricultural land-cover cells within each county. This process involved (1) identifying agriculture land-cover cells within each county using the Anderson Land-Cover Class Code; (2) assigning random identification numbers to each agricultural cell; and (3) writing a module to integrate the AFO/CAFO data sets and distribute loadings to the agricultural land-cover cells.

Figure 7 shows the RF3 network, land-use/land-cover data, and county overlay for one 8-digit HUC. It is onto this mosaic that AFO/CAFO counts by county and associated edge-of-field loadings are distributed. The load distribution module operated according to the following steps:

1. Selected a county using the county FIPS code

2. Generated a list of agricultural cells in that county, ordered by the random identification number.

3. Selected the facility counts for the county. Each county was associated with facility counts for 42 animal type and farm size combinations.

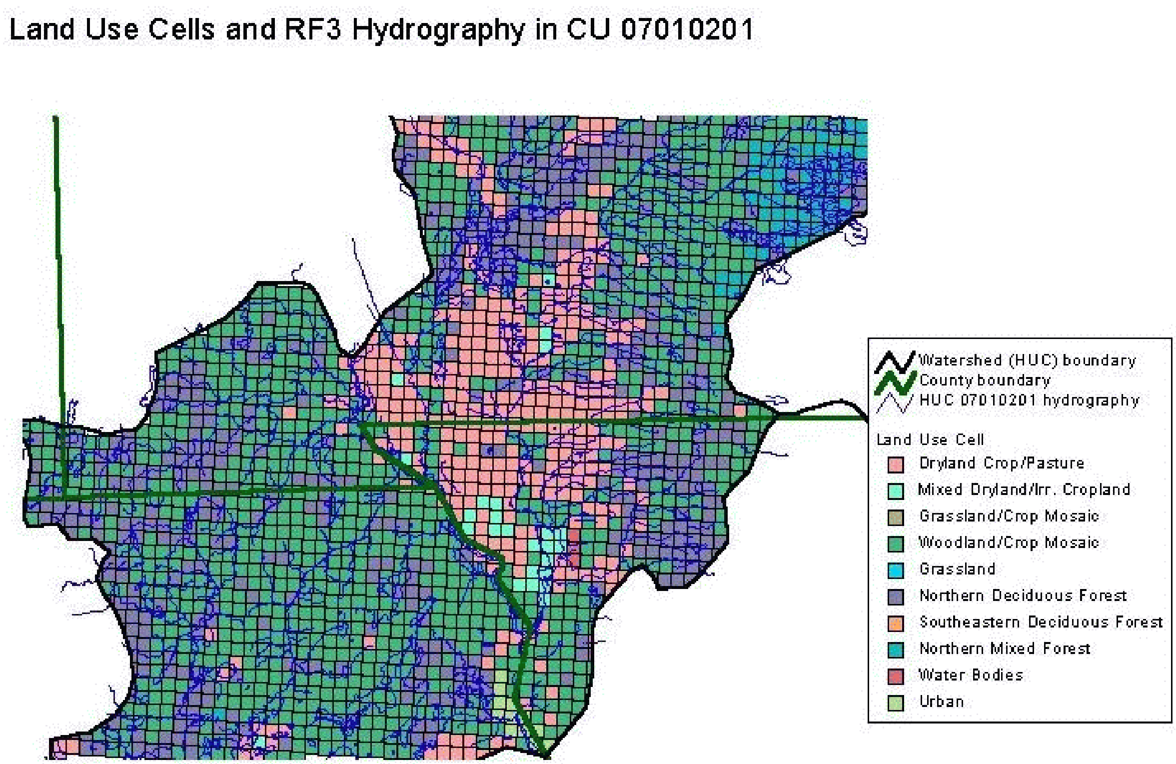

Figure 7. Mosaic Composite of Spatial Data at the Watershed (HUC) Level.

4. Obtain the percentage of AFOs considered CAFOs for each animal type and farm size combination under the regulatory scenario being simulated.

5. Obtained loadings data for regulated and unregulated facilities for each animal type and farm size combination under the regulatory scenario being simulated.

6. Calculated total loadings according to the following equation:

$$\begin{aligned} Species\ Load = &\left(\%reg \times reg\_load \times reg\_species\_fraction\right) + \\ &\left(\%unreg \times unreg\_load \times unreg\_species\_fraction\right) \end{aligned} \tag{25}$$

7. Calculated nutrient species loads by the following equation:

$$\begin{aligned} Total\ Load = &\left(\%\ regulated \times regulated\_load\right) + \\ &\left(\%\ unregulated \times unregulated\_load\right) \end{aligned} \tag{26}$$

8. Calculated the size of the farm in square kilometers using the model farm area. This is equivalent to the number of agricultural land-cover cells onto which the loads will be distributed.

9. Assigned loads to a land-cover cell with sufficient area available. If necessary, distributed loads to additional land-cover cells until the farm area was depleted.

10. Looped through the 42 animal type and operation size combinations until all AFO/CAFO loads in the county were distributed to agricultural land-cover cells.

11. Looped through the 3,045 counties in the conterminous 48 states.

Several rules were applied during the load distribution process to reflect regulatory options or assumptions made during the load development process. These include the following:

- Feedlot loads were not distributed using model farm areas, because of the modeling assumption that these loads have a direct hydrological connection to surface water. Feedlot loads were uniformly distributed to land-cover cells that were less than 100 ft from the nearest RF3 reach, and they did not undergo overland loss or transformation.

- Under RTI Scenarios 1 and 2, a 100 ft. setback was used for land application of manure. Under the setback, regulated manure loadings were not distributed to land-cover cells that were less than 100 ft from the nearest RF3 reach. Unregulated manure loadings were not affected by the 100 ft. setback.

- Commercial fertilizer load distribution was not affected by the 100 ft. setback.

3.3.2 Routing AFO/CAFO Loads to RF3 Reaches

In order to be hydrologically routed through the stream network, the manure and commercial fertilizer loads are routed from the agriculture land-cover cells to the nearest RF3 reach using a routine that simulates overland transport, loss, and transformation. The feedlot loads are routed to the nearest RF3 reach without any loss or transformation of loads. Overland travel times are based on flow in a natural channel such as may be found on agricultural lands (see Section 2.2.4). A unit runoff ($ft^3/sec/km^2$) was derived for each HUC based on data from USGS stream gages in the HCDN network. Travel distances were calculated from the center of the agricultural cell to the nearest RF3 reach.

3.3.3 Routing AFO/CAFO Loads to RF3Lite Reaches

AFO/CAFO loads were routed to the RF3Lite network using an in-stream transport, decay, and transformation module.

3.3.4 In-Stream Modeling in the RF3Lite network

The final stage of in-stream modeling is conducted in the RF3Lite network. At this stage, a module routes through the RF3Lite network according to the hydrologic sequence order. For each reach, NPS, PS, and AFO/CAFO loads at the RF3Lite scale are combined. The loads are decayed and transformed to the middle of the reach to produce an estimate of average in-stream concentration that is inserted into the results table. The loads are then decayed and transformed to the end of the reach to continue routing down the RF3Lite network.

3.3.5 Water Quality Assessment Ladder

NWPCAM 1.6 uses the water quality ladder described in Table 18 to translate in-stream concentration estimates for BOD5, TSS, DO, and FCB into corresponding use-support categories using an approach developed by Vaughn for Resources for the Future (Mitchell and Carson, 1986). This approach assigns maximum pollutant levels for BOD, TSS, and FCB that correspond to boatable, fishable, and swimmable waters. Minimum threshold values are also established for DO. A water resource that fails to meet the boating criteria is classified as a "nonsupport" resource. Vaughn's original water quality ladder included BOD5, turbidity, DO, pH, and FC. In NWPCAM, TSS is used as a surrogate for turbidity.

Table 18. Water Quality Ladder Threshold Concentrations

Beneficial Use	Biological Oxygen Demand (mg/L)	Total Suspended Solids (mg/L)	Dissolved Oxygen (% saturated)	Fecal Coliforms (MPN/100mL)
Swimmable	1.5	10	0.83	200
Fishable	3	50	0.64	1000
Boatable	4	100	0.45	2000

The Vaughn WQL model categorizes reaches as boatable, fishable, swimmable according to the worst pollutant. Benefits are assigned only for reaches that are move across the designated use categories. Thus, for a reach that is classified as "boatable" prior to regulation, even if there is significant improvement in one or more water quality parameters (e.g., TSS and DO) following regulation, no monetized benefit is assigned to that reach if any other parameter remains in the boatable category.

3.3.6 Economic Benefits Calculations Using the WQL

Each RF3Lite reach is categorized using the WQL for each AFO/CAFO regulatory scenario. The difference in the miles for each use category between baseline conditions and a given rulemaking scenario is a measure of the improvement in water quality attributable to the scenario. These differences in miles are converted into economic benefits (dollars) based on the population and their willingness to pay (WTP) for improvement in water quality.

Benefits are calculated state-by-state and are broken down into local and nonlocal benefits. Local benefits correspond to the amount a population is willing to pay for water quality improvements within their own state. Nonlocal benefits correspond to the amount a population is willing to pay for water quality improvements outside of their own state. Local benefits are calculated as follows:

$$\begin{aligned}
BOAT_WTP &= (BOAT_SCN - BOAT_BASE) / seg_length \times pop / 2.62 \times 206 \times C \\
FISH_WTP &= (FISH_SCN - FISH_BASE) / seg_length \times pop / 2.62 \times 155 \times C \\
SWIM_WTP &= (SWIM_SCN - SWIM_BASE) / seg_length \times pop / 2.62 \times 173 \times C
\end{aligned} \tag{27}$$

where

BOAT_SCN	=	miles of the state's boatable waters for rulemaking scenario
BOAT_BASE	=	miles of the state's boatable waters for baseline conditions
FISH_SCN	=	miles of the state's fishable waters for rulemaking scenario
FISH_BASE	=	miles of the state's fishable waters for baseline conditions
SWIM_SCN	=	miles of the state's swimmable waters for rulemaking scenario
SWIM_BASE	=	miles of the state's swimmable waters for baseline conditions
seg_length	=	total miles of RF3Lite reaches in the state
pop	=	population of the state (from 2000)
2.62	=	average number of people per household in the United States
206	=	average annual household WTP (in 2000 dollars) to increase U.S. waters from nonboatable to boatable levels
155	=	average annual household WTP (in 2000 dollars) to increase U.S. waters from boatable to fishable levels
173	=	average annual household WTP (in 2000 dollars) to increase U.S. waters from fishable to swimmable levels
C	=	fraction of WTP applied to local benefits = 2/3.

Nonlocal benefits can also be calculated using Equation 27, with the following variable definitions:

BOAT_SCN	=	miles of the nation's boatable waters for rulemaking scenario
BOAT_BASE	=	miles of the nation's boatable waters for baseline conditions
FISH_SCN	=	miles of the nation's fishable waters for rulemaking scenario
FISH_BASE	=	miles of the nation's fishable waters for baseline conditions
SWIM_SCN	=	miles of the nation's swimmable waters for rulemaking scenario
SWIM_BASE	=	miles of the nation's swimmable waters for baseline conditions
seg_length	=	total miles of RF3Lite reaches outside of the state
pop	=	population of the state (from 2000)
2.62	=	average number of people per household in the United States
206	=	average annual household WTP (in 2000 dollars) to increase U.S. waters from nonboatable to boatable levels
155	=	average annual household WTP (in 2000 dollars) to increase U.S. waters from boatable to fishable levels
173	=	average annual household WTP (in 2000 dollars) to increase U.S. waters from fishable to swimmable levels
C	=	fraction of WTP applied to local benefits = 1/3.

3.3.7 Water Quality Index

McClelland (1974) suggested using a Water Quality Index (WQI) that falls on a continuous scale from 0 to 100, rather than four discrete beneficial-use attainment indicators used in the WQL. The original WQI included nine water quality characteristics: BOD5, DO, FCB, TSS, NO_3, PO_4, temperature, turbidity, and pH. NWPCAM 1.6 uses a six-parameter Water Quality Index (WQI6) that incorporates BOD5, DO, FCB, TSS, NO_3, and PO_4. The remaining three parameters are not modeled in NWPCAM 1.6 and are factored out of the WQI.

The WQI is derived by converting concentrations of each water quality characteristic into a corresponding score (q_i) between 0 and 100. As documented in McClelland (1974), this was accomplished by averaging the judgments from 142 water quality experts regarding the appropriate functional relationship between conventional measures and a 0–100 scale. Appendix B includes charts of the six functional relationships used by NWPCAM 1.6. Weights for each of the scores (w_i) were derived, again based on the summary judgments of the expert panel. These weights were designed to sum to 1 for the nine water quality characteristics. The q_i and w_i values were combined into a composite multiplicative index of the following form:

$$\prod_{i=1}^{n} q_i^{\,wi} \tag{28}$$

The *i* subscript refers to the *i*-th parameter, and *n* is the number of parameters (in this case, $n = 9$). By design, WQI varies between and is bounded by 0 and 100.

To apply McClelland's index to output from NWPCAM 1.6, it must be modified to account for the three characteristics (i.e., temperature, turbidity, and pH) that are not modeled. To accomplish this, new weights are calculated for the remaining six parameters so that the ratios of the six weights are retained and the weights sum to 1. Table presents the original and revised parameter weights for the nine pollutants. Under the revised index, $n = 6$, and the w_i's are specified using the revised weights in Table 19.

Table 19. Original and Revised Weights for WQI Parameters

Parameters	Original Weights	Revised Weights
BOD5	0.11	0.15
DO	0.17	0.24
FCB	0.16	0.23
TSS	0.07	0.1
NO_3	0.1	0.14
PO_4	0.1	0.14
Temperature	0.1	--
Turbidity	0.08	--
pH	0.11	--
Total	1	1

3.3.8 Economic Benefits Analysis Using the WQI6

The following WTP function is used to derive economic benefits using the WQI6 approach. This equation was estimated and reported by Mitchell and Carson using WTP responses from their survey sample.

$$TOTWTP = \exp\left[0.413 + 0.819 \times \ln(WQI/10) + 0.959 \times \ln(Y/1000) + 0.207 \times W + 0.46 \times A\right] \quad (29)$$

where

TOTWTP	=	each household's total annual WTP (in 1983 dollars) for increasing water quality up to each of the three WQI values
Y	=	annual household income (sample average = $24,220 in 1983 dollars)
W	=	dummy variable indicating whether the household engaged in water-based recreation in the previous year (sample average = 0.59)
A	=	dummy variable indicating whether the respondent regarded the nation goal of protecting nature and controlling pollution as very important (sample average = 0.65).

In solving this equation, Mitchell and Carson used Vaughn's WQL to map each beneficial-use category to a corresponding WQI value (boatable = 25, fishable = 50, and swimmable = 70). These values were applied in the right-hand side of Equation 28.

Equation 28 can also be used as a benefit-transfer function, to assess the value of increasing water quality along the continuous WQI scale. In other words, assuming that *W* and *A* are representative of the current population, the incremental value associated with increasing WQI from WQI_0 to WQI_1 can be calculated as

$$\begin{aligned} \Delta TOTWTP = \; & \exp[0.8341 + 0.819 \times \log(WQI_1/10) + 0.959 \times \log(Y)] \\ - \; & \exp[0.8341 + 0.819 \times \log(WQI_0/10) + 0.959 \times \log(Y)] \end{aligned} \quad (30)$$

Y, in this case, would be selected to correspond to average (or median) household income in the year of the water quality change (expressed in 1983 dollars). The resulting value estimates can be inflated to 2000 dollars using the growth rate in the consumer price index (CPI) of 1.72 since 1983.

Benefits are calculated state-by-state and are broken down into local and nonlocal benefits. Local benefits correspond to the amount a population is willing to pay for water quality improvements within their own state. Nonlocal benefits correspond to the amount a population is willing to pay for water quality improvements outside of their own state.

4.0 Results of AFO/CAFO Analyses

This section summarizes the results of the NWPCAM 1.6 analyses for the AFO/CAFO rulemaking scenarios.

4.1 AFO/CAFO Loadings

Total national AFO/CAFO loadings are key inputs estimated by EPA and used to drive the NWPCAM 1.6 model simulations. The AFO/CAFO nutrient and pollutant loadings to agricultural cells and their production area loads input directly into RF3 reaches for baseline conditions and rulemaking scenarios are summarized in Table 20. These represent the total national AFO/CAFO loadings actually distributed to agricultural cells and production area loads input directly into RF3 reaches. According to EPA estimates, nutrients and sediments decline moderately under both scenarios. FCB loads decline slightly under all scenarios. FS loads decline slightly under both scenarios. For further discussion of the AFO/CAFO loading calculations, please see the document entitled "Pollutant Loading Reductions for the Revised Effluent Limitation Guidelines for Concentrated Animal Feeding Operations" in the rulemaking record.

Table 20. National AFO/CAFO Loadings on Agricultural Cells*

Rulemaking Scenario	TN (g/s)	TP (g/s)	TSS (g/s)	Biochemical Oxygen Demand (g/s)	FCB (cfu/s)	FS (cfu/s)
Baseline	3316	5076	958,380	1012	3.29×10^{14}	4.30×10^{15}
RTI Scenario 1	2977	4332	931,008	779	2.91×10^{14}	3.50×10^{15}
RTI Scenario 2	3166	4682	936,444	927	3.22×10^{14}	4.16×10^{15}

* Note: To calculate a loading rate per unit area, the values in this table should be divided by the agricultural area in the country.

The AFO/CAFO nutrient and pollutant loadings in the RF3 network for baseline conditions and rulemaking scenarios are summarized in Table 21. These represent the total national loadings delivered to the RF3 reaches after overland transport from the agricultural cells to the nearest reach occurs (manure and commercial fertilizer loads only). Table 22 lists the delivery ratios to RF3 for baseline and scenarios. Between 75 and 90 percent of the total national loads are delivered to the RF3 reaches for TN, TP, TSS, BOD, FCB and FS.

Table 21. AFO/CAFO Nutrient/Pollutant Loadings to RF3 Rivers/Streams

Rulemaking Scenario	TN (g/s)	TP (g/s)	TSS (g/s)	BOD (g/s)	FCB (cfu/s)	FS (cfu/s)
Baseline	2674	3832	748,148	907	2.52×10^{14}	3.75×10^{15}
RTI Scenario 1	2414	3296	733,841	686	2.20×10^{14}	3.02×10^{15}
RTI Scenario 2	2571	3563	738,741	826	2.48×10^{14}	3.62×10^{15}

Table 22. AFO/CAFO Delivery Ratios to the RF3 Network

Rulemaking Scenario	TN (g/s)	TP (g/s)	TSS (g/s)	BOD (g/s)	FCB (cfu/s)	FS (cfu/s)
Baseline	0.81	0.75	0.78	0.90	0.77	0.87
RTI Scenario 1	0.81	0.76	0.79	0.88	0.76	0.86
RTI Scenario 2	0.81	0.76	0.79	0.89	0.77	0.87

AFO/CAFO loadings to the RF3Lite subset of RF3 reaches for baseline conditions and rulemaking scenarios are summarized in Table 23. These represent the total national AFO/CAFO loadings delivered to the RF3Lite subset of RF3 reaches after transport down the RF3 network to the first RF3Lite reach segment encountered. Table 24 lists the delivery ratios to RF3Lite for baseline and the scenarios. Between 69 and 86 percent of the total national loading are delivered to the RF3Lite reaches for TN, TP, TSS, BOD, and FS. FCB have a high die-off rate, which translates into a smaller delivery ratio at around 62 percent.

Table 23. AFO/CAFO Nutrient/Pollutant Loadings to RF3Lite Network

Rulemaking Scenario	TN (g/s)	TP (g/s)	TSS (g/s)	BOD (g/s)	FCB (cfu/s)	FS (cfu/s)
Baseline	2383	3502	683,817	875	2.05×10^{14}	3.53×10^{15}
RTI Scenario 1	2149	3007	670,391	663	1.80×10^{14}	2.84×10^{15}
RTI Scenario 2	2290	3252	674,921	798	2.02×10^{14}	3.40×10^{15}

Table 24. AFO/CAFO Delivery Ratios to the RF3Lite Network

Rulemaking Scenario	TN (g/s)	TP (g/s)	TSS (g/s)	BOD (g/s)	FCB (cfu/s)	FS (cfu/s)
Baseline	0.72	0.69	0.71	0.86	0.62	0.82
RTI Scenario 1	0.72	0.69	0.72	0.85	0.62	0.81
RTI Scenario 2	0.72	0.69	0.72	0.86	0.63	0.82

4.2 Economic Benefits

Table 25 provides a summary of the annual economic benefits for each scenario using the WQL. This summary was computed by summing the local and nonlocal benefits for each state. Scenario 1 exhibited a higher benefit because of its layer reduction of all constituents.

Table 25. Annual Economic Benefits Using the WQL (2001 dollars, thousands)

Rulemaking Scenario	Boatable Waters*	Fishable Waters*	Swimmable Waters*	Total Benefit
RTI Scenario 1	114,051	38,811	13,322	166,184
RTI Scenario 2	73,065	23,202	6,122	102,389

* Boatable benefits include only those benefits attributable to improvements from non-boatable to boatable. Benefits from improvements to other beneficial use categories appear in the other columns. For a reach that improved from nonbotable to fishable, for example, a portion of the benefits appear in the boatable column, and the remainder appears in the fishable column. Similarly, fishable and swimmable benefits include only those benefits attributable to improvements from boatable to fishable and from fishable to swimmable, respectively. Benefits from improvements to other use categories appear in the other columns as described above.

Table 26 provides a summary of the annual economic benefits for each scenario using the WQI. This summary was computed by summing the local and nonlocal benefits for each state. Scenario 1 exhibited a higher benefit because of its layer reduction of all constituents.

Using the WQL, the bulk of monetary benefits occur in the boatable waters category. Using the WQI, the majority of the benefits occur in the middle (i.e., 26<WQI<70) category. The total estimated benefit using the WQI is substantially larger than the benefit using the WQL. Both of these conditions are a result of the process used to categorize improvements in water quality in each of the models. In the WQL model, reaches are categorized into designated uses according to the worst pollutant, and benefits are assigned only for reaches that move between designated use categories. In the WQI model, reaches are assigned WQI values between 0 and 100 using a weighted average function to determine overall water quality. A WTP function was developed that interpolates what people are willing to pay along the continuous 0–100 scale. Therefore, any improvement in water quality is included in the benefit using the WQI model.

Table 26. Annual Economic Benefits Using the WQI (2001 dollars, thousands)

Rulemaking Scenario	WQI < 26	26 < WQI < 70*	WQI > 70**	Total Benefit
RTI Scenario 1	10,088	24,154	46,950	298,552
RTI Scenario 2	7,187	135,266	40,105	182,558

* This category includes only the benefits attributable to improvements between 26 and 70. For example, for a reach that improved from 24 to 30, the portion of benefits attributable to the increase from 24 to 26 appears in the WQI<26 category; the remainder appears in the 26<WQI<70 category.

** This category includes only the benefits attributable to improvements to a WQI >70. For a reach that improved from 24 to 80, for example, a portion of the benefits is allocated to each of the WQI<26, the 26<WQI<70, and the WQI>70 categories.

4.3 Discussion of Benefit Results

Both estimation methods rely on WTP values derived by Carson and Mitchell (1993). The WQL captures the benefits of discrete changes in the type of uses or amenities provided by waterbodies and, in doing so, reflects the principles of water quality standards where determinants of beneficial use attainment are based on water quality criteria. Carson and Mitchell (1993) indicate that amenities such as boatable, fishable, and swimmable water quality are "concepts that are widely understood."

However, the pollutant criteria for making use determinations in the discrete ladder include criteria for which federal guidance has not been developed. Criteria for TSS and BOD are not typically adopted for the boatable, fishable, and swimmable amenities, and inclusion of criteria for these pollutants implies lower probability of beneficial use attainment under the ladder than might be indicated by other methods for determining use attainment in the nation's waters.

In contrast, the WQI approach adopted for this final rule characterizes changes in water quality using an aggregate index derived from six individual pollutant concentrations. Carson and Mitchell (1993) state that the use of this type of index greatly facilitates the task of communicating the several quality levels (i.e., amenities) to the (survey) respondents. This observation accentuates the fact that different respondents are likely to rely on different measures of water quality to make value judgments. The minimum index values (25 for boatable, 50 for fishable, and 70 for swimmable) adopted by Carson and Mitchell help explain why the magnitude and distribution of benefits differ between the discrete ladder and the continuous WQI approaches.

Differences in magnitude are due in part to the likelihood that the distribution of predicted changes in some parameters is not sufficiently large to meet criteria necessary for an amenity change, including the boatable category. As a consequence, changes in beneficial use are unlikely to occur, and corresponding benefits are lower under the discrete ladder. Under the continuous WQI, benefit estimates are not constrained by "limiting parameter" distributions, and the benefits from all changes in water quality are captured, regardless of changes in amenity support. The relative difference in magnitude of benefits is a function of the baseline distribution of water quality parameters; in some special cases, the benefits under the ladder could approximate or even exceed those under the continuous index (when baseline measures of central tendency (e.g., median) are approximately equal to the threshold criteria for supporting amenities).

Apparent inconsistencies in the distribution of benefits between the two methods arise because many waterbodies fail to meet beneficial use criteria in the ladder, yet most of these same waterbodies have WQI values that exceed the minimum index thresholds specified in the ladder. For example, most of the benefits realized under the ladder occur when waters improve from nonboatable to boatable because, as noted above, a majority of waterbodies are not capable of meeting the criteria for higher uses. However, in the case of the continuous index, a majority of benefits are due to changes in water quality within an index range of 26 to 70; this range reflects a boatable and/or fishable attainment, based on index thresholds in the ladder (boatable = 25, fishable =50, swimmable = 70). The discrepancy occurs because many nonboatable reaches under the ladder actually have index values that are far higher than the minimum threshold for boating. Approximately 80 percent of reach segments designated as nonboatable under the ladder under baseline conditions have WQI values that range from 29 to 79 based on NWPCAM output for a four-parameter index, implying that many waterbodies deemed nonboatable under the ladder would be considered boatable, fishable, or even swimmable under the continuous index. It is felt that many people would be willing to boat or fish in waters that are deemed unboatable under the ladder. As a final note regarding the distribution of benefits, it is also possible that a particular regulation, such as the final CAFO rule, may affect specific geographic areas where nonboatable waters predominate, thus implying that a majority of benefits are attributable to improvements from nonboatable to boatable.

A comparison of the two valuation methods is most easily understood within the context of the original Carson and Mitchell survey. Recall that the Carson and Mitchell survey presents (1) explicit relationships between beneficial use categories and numeric values of the WQI, and (2) baseline water quality conditions for the nation that are similar in some respect to the results in the NWQI (2000). The results from the survey are used to estimate (1) mean WTP values for water quality levels supporting different amenity categories, and (2) a valuation function that predicts WTP as a function of water quality index values. The ladder approach to estimating benefits maintains consistency with the explicit correlation between WTP and beneficial use categories specified by Carson and Mitchell (e.g., a change in water quality and WTP can be related to changes in amenities), but is not consistent with baseline water quality conditions. The WQI approach maintains consistency with baseline water quality conditions but is less capable of maintaining consistent relationships between WTP and changes in beneficial use categories. Other advantages of the continuous index approach include (1) use of a decreasing marginal benefits curve with respect to the WQI (consistent with economic theory), (2) the ability to capture benefits of marginal changes in individual water quality parameters without triggering changes in amenities, and (3) the ability to capture benefits associated with changes in other parameters (i.e., nitrate and phosphate) that are not included in the ladder.

5.0 Quality Assurance

Potential sources of error and uncertainty in the analysis include model inputs (e.g., hydrologic inputs from RF3), data processing, model parameters (e.g., decay rates), and benefits monetization methods. This section describes measures taken to reduce these errors and uncertainties for the AFO/CAFO analysis, including (1) reviewing hydrologic inputs for reasonableness, (2) evaluating the robustness of model predictions to changes in model parameters, (3) performing quality assurance on all data processing steps, including the computational modules, (4) evaluating modeling results for reasonableness, and (5) evaluating the sensitivity of estimated benefits to the monetization method selected.

5.1 Reviewing Hydrologic Inputs

RTI has performed extensive quality assurance on the flow and velocity estimates included in NWPCAM 1.6. Comparisons were made between NWPCAM 1.6 and observational values of flow and velocity obtained from the USGS HCDN network. The results of this work, including the methodology used to develop the NWPCAM 1.6 estimates, are contained elsewhere (RTI, 2001).

5.2 Model Robustness

A full calibration exercise on NWPCAM 1.6 has not been conducted. However, a sensitivity analysis was performed in Hydroregion 5 to evaluate changes in predicted water quality due to changes in modeling inputs (RTI, 2002). Ten parameters (i.e., flow, velocity, depth, PS loads, non-AFO NPS loads, BOD oxidation rate, TSS settling rate, FCB die-off rate, sediment oxygen demand, and CBODU:BOD5 ratio) were varied by a factor of 1.5 to 2. Because NWPCAM is a screening-level model, the sensitivity analysis was aimed at evaluating whether changes in water quality from baseline to scenario were robust, as opposed to absolute water quality. Four model runs were conducted for each of the 10 parameters: (1) low parameter value, baseline AFO/CAFO loads; (2) low parameter value, scenario AFO/CAFO loads; (3) high parameter value, baseline AFO/CAFO loads; and (4) high parameter value, scenario AFO/CAFO loads. For these analyses, the baseline AFO/CAFO loadings were taken from the dummy loadings files supplied by EPA on March 27, 2002. Scenario loadings were taken from Option 2 in the same dummy loadings file.

Flow, velocity, and non-AFO NPS loads had the greatest impact on absolute water quality as assessed by the WQI6. However, changes in water quality were robust, with average WQI improvements of approximately 1.3 for all runs. This indicates that uncertainty in model coefficients and inputs may not have a significant impact on predicted water quality changes under regulatory scenarios. However, absolute model results (e.g., DO concentrations by reach) will be affected significantly by uncertainty in model coefficients and inputs.

5.3 Data Processing

The compatibility between AFO/CAFO loads distributed onto agriculture cells and AFO/CAFO input files was checked using a hand calculation. Table 27 shows the AFO/CAFO loads distributed in Vermont using the two methods.

Table 27. Verification of Loads Distribution Module

Method	TN Load (g/s)	TP Load (g/s)	TSS Load (g/s)	FCB Load (MPN/s)	FS Load (MPN/s)
Manual	10.99	16.14	1.388	1.21×10^{10}	6.62×10^{10}
Module	11.02	16.17	1.391	1.21×10^{10}	6.66×10^{10}

A shapefile was created in ArcView 3.2 under baseline regulations to confirm that high loadings occur in rural areas (see Figure 8). The shapefile was also used to identify counties with zero AFO/CAFO loadings. Five of these counties were selected to confirm they did not have associated animal farms in the input files.

Other quality assurance steps include the following:

- A check on the data import from Excel to Oracle by summing across columns and comparing column totals.

- A qualitative comparison of loads reductions was conducted between scenarios to ensure reasonableness based on technology options and/or percent of regulated facilities. It confirmed that higher loads in NPDES scenarios agreed with smaller state percentages in medium categories.

- A check on the loading distribution algorithm by summing the number of land-use/land-cover cells receiving loads. To compare loads distribution between baseline and scenario, confirmed that fewer Layer A land-use/land-cover cells (i.e. < 100 ft from the nearest RF3 reach) received loads for the scenario (due to the 100 ft setback).

- A check on the delivery ratios calculated for each run. Delivery ratios from land-cover cells to the RF3 network were compared to literature values and found to be within acceptable ranges (SCS, 1983).

5.4 Modeling Results

Checks have been made on the distributions of predicted water quality for FC and TSS. FC water quality standards are typically expressed in terms of geometric means. For example, EPA water quality criteria suggest a geometric mean of 200 MPN/100mL as a guideline for swimmable waters (U.S. EPA, 1986). Mean values of 100 to 200 MPN/100 mL were calculated in Hydroregion 1 after a log transform was applied to the FC concentrations.

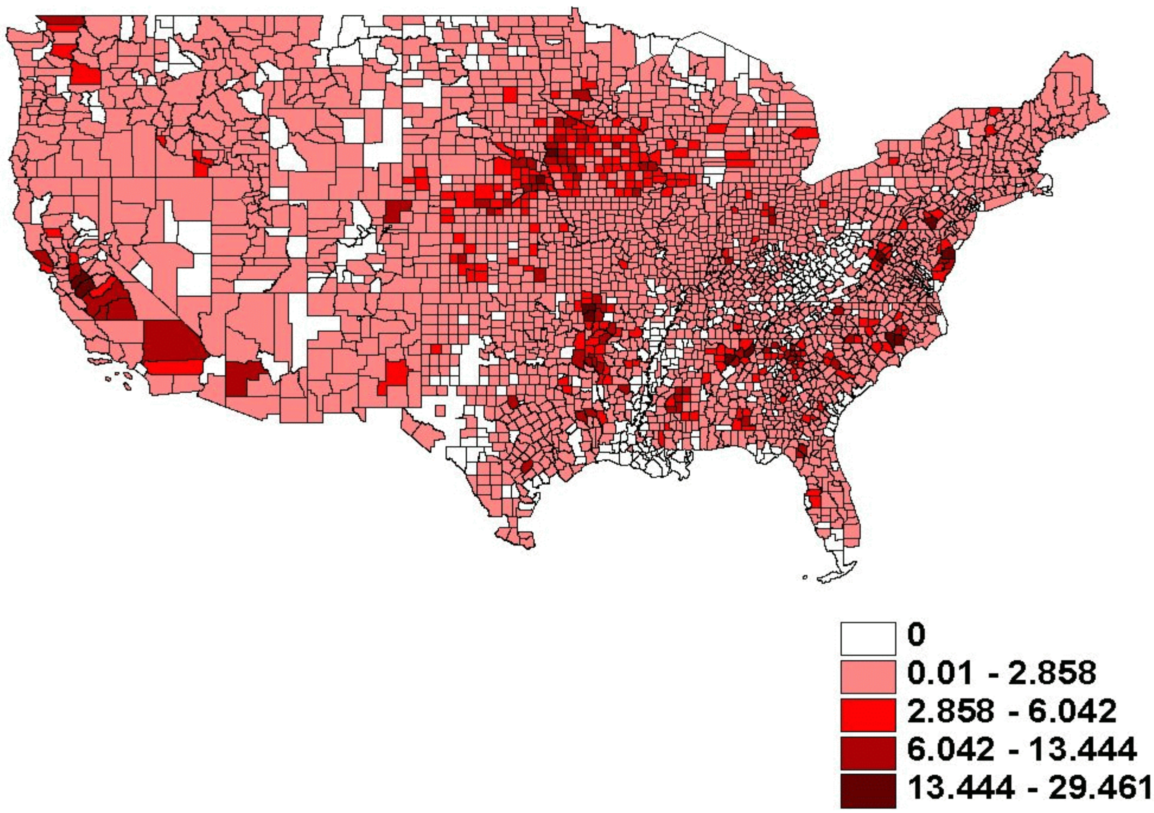

Figure 8. Total nitrogen loadings (g/s) by county FIPS code for baseline.

General comparisons of baseline results to National Stream Quality Accounting Network (NASQAN) data for TSS, TN, and TP developed by EPA staff show similar ranges of values and patterns of high and low values.

Other quality assurance steps include the following:

1. An examination of individual use-support for each run to assess reasonableness of overall use-support and differences between scenarios (i.e., examined that changes in individual use-support agreed with changes in loadings).

2. An examination of estimated benefits per mile of improvement. For RTI Scenario 7, a geographic analysis was conducted to justify the large estimated economic benefit.

3. A hand calculation of miles affected under Scenarios 6 and 7 using the Vaughan WQL.

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